

# A versatile methodology for preventing a parallel transmission system using impedance-based techniques

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## Article Info

### Article history:

Received Sep 26, 2022

Revised Jan 4, 2023

Accepted Jan 29, 2023

### Keywords:

Adaptive protection  
Cross-sectional technique  
Digital relaying  
Impedance-based technique  
Mutual coupling effect  
Parallel transmission line

## ABSTRACT

The various configurations that exist for a compatible circuit depend on an object, such as operating conditions, the occurrence of an inter-circuit error and the result of the coupling of the transmission line. This feature makes the protection of the same transmission lines very difficult. This paper introduces a new algorithm based on a state diagram that contains location data collected on a passing bus. Combine the different separation processes and the impedance-based process is used. The classification process cannot detect internal errors and only compares with existing phases where the same regional error occurs in the 2D space and the impedance-based method used to cover the resulting error. The proposed algorithm incorporates impedance-based methodology and separation technology to provide the appropriate response under all operating conditions of the same circuits.

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## 1. INTRODUCTION

Parallel transmission lines are all now widely used in the electrical network and they're less expensive to develop than new designs. That alone ensures this same transmitting line's dependability and safety [1]. Because of their higher frequencies, parallel configuration power lines set up in the same towers are used on high-voltage transmission implementations. But the factors like the mutual coupling effect, inter-circuit faults, external faults, and the faults that occur due to different operating conditions of the parallel transmission line make the protection of a parallel transmission a challenging task [2]. The current differential protection scheme using a communication link between the ends of the transmission line could provide accurate protection of the parallel transmission line. But the reliability of the transmission line is directly proportional to the reliability of the communication links hence the protection system could use the algorithm which depends on the local information available at the relay point will help the protection system of the parallel transmission line for accurate fault detection and mitigation [3].

If a traditional distance relay is being used to protect a parallel transmission system, mutual inductance has an effect on the distance relay's performance [4]. When both line segments are operational, if the distance relay is established to secure 80% of the total of the transmission network, and besides based on mutual linkage, this only protects 50% of the line. In contrast, when one of the lines has been out of the system or grounded at both endpoints, the distance relay would provide 100% coverage [5], [6].

It is important to remember that the transmitting stage will be lowered due to the effect of the exchange between the same connection if the typical range has been carried out to defend the related sections. For a reliable transmission sequence, if the distance transmission configuration is set to 85% of the impedance line, then only half of the overhead lines will be covered. Today, a transmitter can have coverage of more than 100% if one of the identical circuits is dormant and deeply implanted at both ends [7]. Capacitive reactance, fault resistance, and the implications of mutual coupling all affect the performance of distance relays. It causes problems in the functioning of the distance relay. To ensure the distance relay functions accurately, various filtering methods are being implemented. They include wavelet filtering, rapid Fourier transform, and prony filtering. However, a distance relay's effectiveness is affected by several factors, including its capacitive reactance, fault resistance, and mutual coupling.

Innovative algorithms prevent this [8], [9]. One method safeguards the entire transmission line. Terminal-based functions include cross-differential. The cross-differential approach compares parallel circuit current phasor magnitudes. When two current phasors surpass the threshold value, it detects an inter-circuit fault [10], [11]. Cross differential protects the line from mutual coupling and responds faster than distance protection. Comparing parallel circuit phases' impedances is another option. One such approach is activated if both circuits appear active and disabled otherwise. Nonetheless, this method may be better at detecting transmission line end distant site defects [12]. A nonpilot-based parallel electrical transmission protection methodology describing distant circuit breaker (CB) operation has been utilized to find remote defects. Superimposed currents can detect remote CB openings [13]. During transmission line, and internal fault conditions, the distance relay's second zone operation has been sped up. However, such a technique must be tested for changing faults, where the problem expanded to other phases after a time delay [14]. An evolutionary defect may misunderstand the superimposed waveforms as a remote CB, causing the relay to operate improperly.

The article explains a method for safeguarding dual-circuit transmission lines using a state diagram. The proposed method combines the results of the impedance-based approach and the crossover method [15], [16] to deliver a protection system that is both faster and more reliable. To compare the phases of the currents in parallel circuits, a novel cross-differential approach is created. The complete range of operational states in a two-dimensional space has been partitioned into six parallel regions [17]–[19]. The frequency-division differential strategy is not always capable of spotting internal faults; hence an additional impedance-based method has been utilized to cover all possible mistakes. By simulating a parallel connection across a sliced-up two-dimensional domain, the impedance-based method effectively recreates the mutual coupling effect [20]–[22]. In certain operational situations, the residual current of the grounding circuit is to be expected when one of the parallel circuits breaks and both ends were mostly grounded. The suggested method identifies transmission line functionality in addition to including the end of the transmission line, and it is based on a state diagram that makes use of the transition sequence between distinct defined states to handle particular faults. Have made use of the CB that was cut out of the tree [23]–[26]. Section 2 outlines the system relay's traditional operating principle. Section 3 outlines the system state diagram based on state logic, and in section 4, we conclude that, compared in comparison to other algorithms, the suggested methodology appropriately as well as efficiently encompasses inter-circuit and evolving faults. Furthermore, this protects the transmission line's end by detecting the functioning of the remote-end CBs.

## 2. PROPOSED RELAY

The full circuit diagram of the double-circuit transmission network in use to evaluate the novel methodology is shown in Figure 1. A single-pole tripping operation is used by the CB. The given methodology is used to secure the system by opening the CB of all phases after discovering interior problems, even if the single-pole tripping functionalities are not usable.

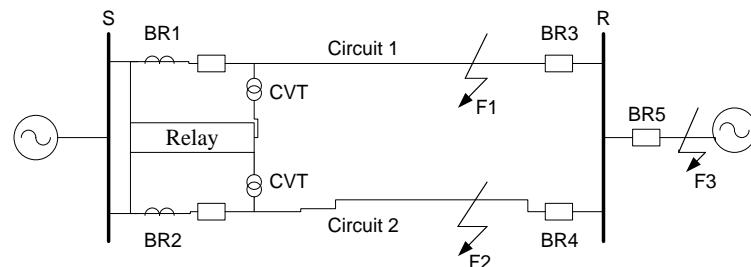


Figure 1. Transmission circuit layout with two circuits

### 2.1. Presented 2D space cross-differential method

The fundamental concept of the cross-differential method is based on comparing the current phases of a parallel transmission network. The current balanced relay's status is indicated by:

$$|I_1| - |I_2| > I_{op} \Rightarrow \text{Trip circuit 1} \quad (1)$$

$$|I_2| - |I_1| > I_{op} \Rightarrow \text{Trip circuit 2} \quad (2)$$

Where  $I_1$  represents the current in phase circuit 1 and  $I_2$  represents the current in phase circuit 2. Whenever the variation in magnitude between parallel circuit currents increases a top threshold, the relay sends a trip command to a CB. The highest imbalance identified during the non-faulty condition has been used to determine the threshold value. Meanwhile, whenever a remote fault happens on one of the circuits, the variation in the magnitude of the current of the parallel connection is much less than the prescribed level of threshold current, and the cross-differential methodology has been unable to cover the full length of the transmission network.

Since both phases of a double circuit line have become operational, the cross-differential method is well because it does have high sensitivity as well as fast fault clearing. Whether any of the lines is not operational, the characteristics also aren't met, and the cross-differential methodology could fail to prevent relay mal-operation. Also, as consequence, the suggested methodology could be incapable of resolving evolving flaws. In the case of SPT, the traditional cross differential relay wrongly trips this same healthy section after the SPT operation of the CB tries to open the fault occurs section. Figure 2 depicts the current waveforms of phase c on circuit 1 of the parallel transmission line, which is where the line to ground (LG) fault is generated. After the 20s, the issue on bus  $S$  is fixed by SPT. As soon as the issue is fixed, the phase C current in the unfaltering part of the circuit rises, while the current in the faulted part of the circuit begins to fall. As seen in Figure 3, this state of affairs persists until the breaker opens the faulty part, resulting in a false tripping of the healthy section.

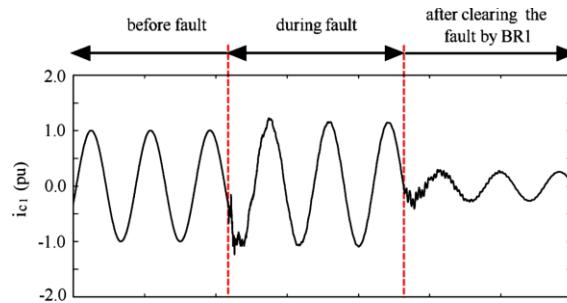


Figure 2. Current waveforms during LG fault of circuit 1

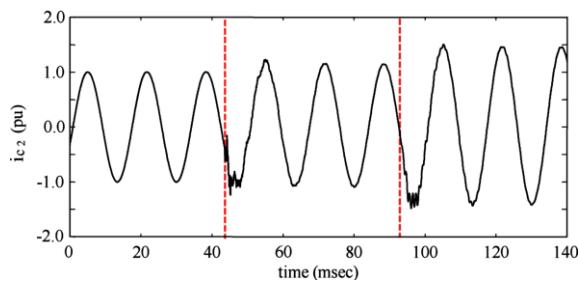


Figure 3. Current waveforms during LG fault of circuit 2

Inter-circuit failures between two different phases have the same issue. To prevent the asymmetric current from exceeding the threshold level in the healthy portion of parallel circuits during single faults, the threshold current value must be set appropriately. This technique lessens the need for relays to safeguard the parallel lines end from a cross differential. In Figure 4, we see the cross-differential method in action, segmenting a two-dimensional space. Using the potential scenarios of the power network under different circuit operating conditions, we can classify six sectors.

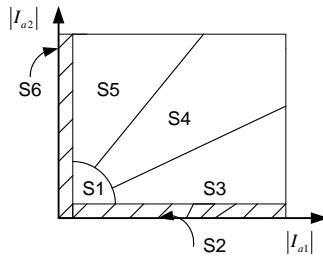


Figure 4. Illustrates the suggested cross-differential computation 2D space segmentation

There are a variety of power network conditions in each region, which are summarized in Table 1. The proposed method accommodates all possible operational states of parallel circuits, and it need not be disabled anytime one of the circuits is down. However, additional conditions are taken into account in particular regions (i.e., S1, S2, S4, and S6) to distinguish internal problems happening on the protected transmission network. This is because, as shown in Table 1, many alternate scenarios for the local electrical grid have become practicable in these areas.

Table 1. Feasible conditions corresponding to various regions of the suggested 2D cross-differential relay

Area	Transmission system condition.
S1	Normal load condition.
	Internal and external faults when the impedance of the source is very high.
S2	Circuit 2 is out for service, with Normal load conditions.
	An external fault on circuit 1 when circuit 2 is not in operation.
S3	A fault occurs on circuit 1 of a parallel transmission line.
S4	A remote fault occurs on both circuit 1 and circuit 2 when both are in operation.
S5	A fault occurred on circuit 2 of a parallel transmission line.
S6	An external fault occurs when circuit 1 is not in operation.
	Normal load condition.

## 2.2. Adjacent line zero-sequence current adaptive compensation

Incorrect distances relay functioning may occur as a result of the mutual coupling effect of a parallel transmission line on phase voltages. One of the parallel circuits failing to work properly and becoming grounded at both ends is the worst-case situation. Because of this, external faults that are far from the remote bus may be apparent within the first protective zone of the relay, even though the relay is designed to protect only against faults within its range. A compensating factor improves the accuracy of the measured impedance of a faulted circuit, but it also causes false tripping of a healthy circuit. A suggested two-dimensional cross-differential methodology includes an appropriate method for assessing if the impedance should have been determined even without mutual coupling compensation. If the current locus would be in the second or third quadrant, the impedance has been estimated with mutual coupling compensation in which compensation wasn't given to circuit 2.

However, if the current locus has been in a second or third quadrant, impedance has been determined with mutual coupling compensation, even if compensation wasn't presented to circuit 2. If the locus has been between the first and fourth regions, mutual coupling compensation has been applied to both parallel circuits. As shown in Figure 5, the current transformer has been assembled behind its CB, so that when the CB has been opened, the relay cannot connect directly to the current of the corresponding line. When one of the circuits is turned off and both ends are grounded, of that kind situations exist. By connecting additional CT the current will compensate but it is not practically possible. The suggested method solves this issue by using relay data to calculate an estimate of the zero-sequence current in the grounded circuit. For Figure 5(a) the formula for the current in the zero sequences when circuit 2 is off and both ends are grounded is (3):

$$I_{SO2} = \frac{\alpha \cdot Z_{0m12} \cdot I_{SO1} - (1-\alpha) \cdot Z_{0m12} \cdot I_{R01}}{Z_{12} + Z_{02}} \quad (3)$$

Mutual coupling impedance between circuits 1 and 2 is denoted as  $Z_{0m12}$ , where  $I_{SO1}$  and  $I_{R01}$  represent the zero-sequence currents at the transmitting and receiving ends of circuit 1 respectively. The positive zero sequence impedance is denoted by  $Z_{01}$ , and the negative impedance is denoted by  $Z_{02}$ . The distance between the site of the failure and the relay, measured in power units, is denoted by. Relay-to-fault-point distance on a per-unit basis. The formula for the zero sequence current in a grounded circuit is (4):

$$I_{SO2} = \frac{Z_{0m12} \cdot I_{SO1}}{Z_{12} + Z_{02}} \quad (4)$$

Two scenarios of parallel circuit configuration is depicted in Figure 5, where only one circuit is functioning at a time. As can be seen in Figure 5(a), in the initial state, the zero-sequence current is flowing through the ground return. Figure 5(b), the zero-sequence current is absent in condition 2. Voltage readings are close to zero when the power-off circuit is grounded at both ends. When both ends of a circuit are disconnected, the induced voltage from the two parallel interconnects will cancel out, and the measured value will be the same as the open-circuit voltage. Thus, the proposed method always assumes that (3) is fulfilled for grounded sections and the zero-sequence current is zero for ungrounded sections.

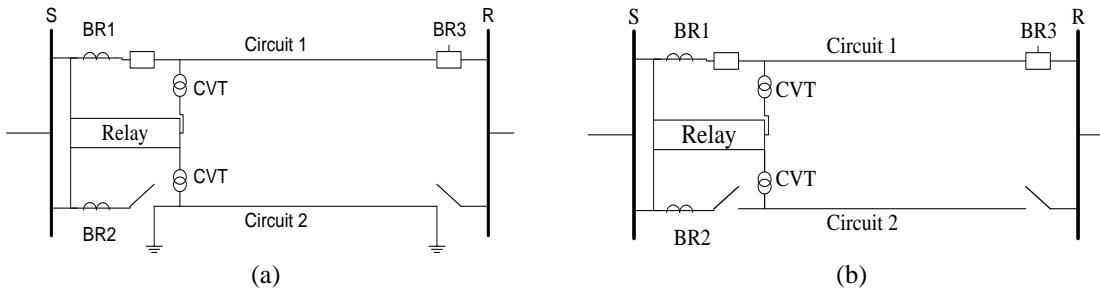


Figure 5. Parallel circuit configuration (a) power off circuit is grounded at both ends and (b) power-off circuits are open at both ends

### 3. STATE DIAGRAM-BASED DECISION-MAKING LOGIC PROPOSED

The whole work presented a state-diagram-based technique that combines impacts of opposite division with impedance-based techniques. Throughout this manner, a sequence of events distinct from the transfer system could be observed, facilitating the transition of quick and reliable judgments. It really should be mentioned that incorporating multiple transfer releases with the basic thing "OR" does not address the issues they could encounter in the same line of safety. For illustration, if the transmitted impedance has been used to prevent parallel lines from traveling differently, this could construct a faulty route to the positive line besides confronting the closest line.

In another instance, whenever one of the same lines seems to be closed, standard separation techniques must be deactivated needed to reduce false positives in the service line. As a third scenario, whenever a remote error occurs at the end of a portion of a transmission line, none of its most common orders to distinguish based on the discriminatory impedance error seems to be applicable. The suggested impedance methodology has been divided into two modules that are protected for circuits 1 and 2. Each impedance module has been composed of six components. Three of such essentially concerned only those errors in the sub-protection classification that have been involved in the error for each category (e.g., category A, G, -, and - the materials used). Whenever one of the following techniques has been satisfactory, the outcome of each item has seemed.

- The approximate impedance of the feature is found within the original protection zone.
- When an object's limiting impedance is detected inside the second safety zone, the associated countdown clock has run out. In contrast to conventional range transmission, the suggested approach finds multiphase faults using phase unit extraction. It is up to the class attributes in each unit category to decide if the fault involves a protected category or associated circuits. This method of testing the impedance modules' output with a cutting-edge classification algorithm guarantees that any faulty parts will be identified in the event of inter-circuit faults. Meanwhile, the state according to the same circuits in a different 2-D environment compensates for the effect of collaboration between the same circuits. For the sake of clarity, we received some notices all over the paper to demonstrate how we could make up for the reunion. Please continue with a description of the impedance modules that include the loop-loop errors estimated without accounting for the impact of cooperation between the same circuits.

It has also been demonstrated that the overall effect of these is compensated for using zero algebraic currents and that the loop-loop impedance has been calculated using zero sequences of the adjoining circuit. The six provinces have been described due to differing spatial conditions of the circular circuits in the 2-D spacing, as shown in Table 2. The graphic-based method developed by the government has been intended to conduct in-depth research and computation analyses under various conditions. Figure 6 illustrates the proposed method which is divided into three parts for clarity, so each category has been described separately.

Part I: the first section of the suggested method is depicted in Figure 6(a). So both circuits seem to be operational, this somehow encompasses internal inconsistencies by one of them. A fault in region 1 would cause the appropriate circuit cycle locations to shift from their usual state (say, Location  $S_1$ ) to Location  $S_3$ . In this instance, we have resolved an internal problem in region 1 and sent a trip order to the corresponding CB  $B_{R1}$ . If  $B_{R1}$  is released, the system will transition to state 6 and the current in the negative circuit's corresponding phase will decrease to zero. There may be local currents in the  $S_5$  region before the end of the year. It's possible that the healthy region's twin region won't return to normal until the problem is fixed by opening the remote CB  $B_{R3}$ . A rise in output from the impedance module, indicating an increase in line impedance and an associated error, begins at time value 6.

Compensation for the outcome of the merger is explicitly excluded from this. This is done so that when proximity errors occur in one part of the world, they won't be mistaken for favorable results in a healthy part of the world. State 3 locus currents will transition to state 4 if the fault is not corrected and circuit 2 is reset to the same phase before  $B_{R1}$  is closed. Here, performance has been employed to identify a mutable node in circuit 2 and agitate the associated CB2  $B_{R2}$ . When an error occurs in circuit 2, the  $S_5$  region continues to experience the same circuit's current magnitude, and a dispatch signal is sent to the  $B_{R2}$  conductor of the associated circuit. The system enters condition 2 when the current in the associated phase drops to zero after  $B_{R2}$  has been opened. In region 2, the impedance module begins making line impedance estimates, and this estimation process is flawed regardless of the level of the output.

Table 2. Conditions of transmission lines under various states

State number	Description
1	The locus of the two circuit currents is inside area $S_1$
2	The locus of the two circuit currents is inside area $S_2$
3	The locus of the two circuit currents is inside area $S_3$
4	The locus of the two circuit currents is inside area $S_4$
5	The locus of the two circuit currents is inside area $S_5$
6	The locus of the two circuit currents is inside area $S_6$

Part II: Figure 6(b) shows the second part of the diagram of the proposed state algorithm. The rotating area of the same circuits may remain within the  $S_4$  area under a variety of conditions (i.e., remote errors from the same line, inter-circuit errors covering the same sections in both regions, and external errors). Table 3 summarizes the possible sequence of state changes in various contexts. The suggested methodology employs cutting-edge switch sequences to detect remote inaccuracies just at the end of the line, which can be handled by basic separation transmission as well as impedance transmission. For example, a remote error in region 1 is quickly identified as a proximity error with a transmission attached to a remote bus. Therefore, long-term transmission can disable compatible CB  $B_{R3}$ .

If  $B_{R3}$  is open, the twin phase current in the functional circuit will increase (i.e., circuit 2). As the strain on the system lessens, as shown in Figure 6(b), the system changes from state 1 to state 2 or state 3 as appropriate. This particular scene involves a trip command being issued to CB  $B_{R1}$  after a remote malfunction on circuit 1 was detected. In a like fashion, if a remote fault is detected on circuit 2, the remote relay will trip CB  $B_{R4}$ , which will then cause the system to transition to either state 5 or state 6 depending on the load. At all times, this scenario involves the establishment of a remote fault on circuit 2 and the subsequent imposition of a trip command on CB  $B_{R2}$ . As a result of disturbances from the outside, the system transitions from state 1 to state 4. A fault remains in state 4 until the associated protective relay clears it. Once the outside cause of the problem has been fixed, the system will revert to state 1.

Next, impedance modules and secondary safeguards were added to the long-distance transmission system. Modules that do this measure currents in a zero-crossing and utilize that information to determine impedance, compensating for the effect of mutual coupling. CBs  $B_{R1}$  and  $B_{R2}$  will trip to disassociate the fault if the external fault is not rectified before the 2<sup>nd</sup> zone timings expire. The locus of parallel circuit currents may also be within region  $S_4$  in the event of inter-circuit failures involving phases shared by both interconnects. Such malfunctions are shielded by the impedance modules. In addition to rapid operating rates for faults in the first protective zone, the impedance modules also contain the line terminal end in the 2<sup>nd</sup> protective zone. It should have been noted that due to the configuration of three phases on the structural system, such inter-circuit faults take place infrequently in practice 3).

Part III: Figure 6(c) depicts the third part of the suggested technique. It can be used to prevent the transmission system whenever one of the parallel connections fails. In the last section, we discussed how the relay might not have had access to the zero-sequence current of the disconnected circuit because of the way the current transformers were set up. It changes to state 2 when the phase currents in circuit 2 are zero, which

happens when the circuit is shut off. If the line impedance output has grown significantly during state 2, this indicates a problem. In state 6, the mutual coupling effect is compensated for using the approximated zero-sequence current; this is achieved by preventing the distance relay first zone overreach, which would otherwise cause unnecessary tripping due to external faults far beyond the remote bus equally upon turning off circuit 1. When the transmission system is included throughout (state 6), the impedance module keeps a constant eye on the line impedance and shuts it down if necessary.

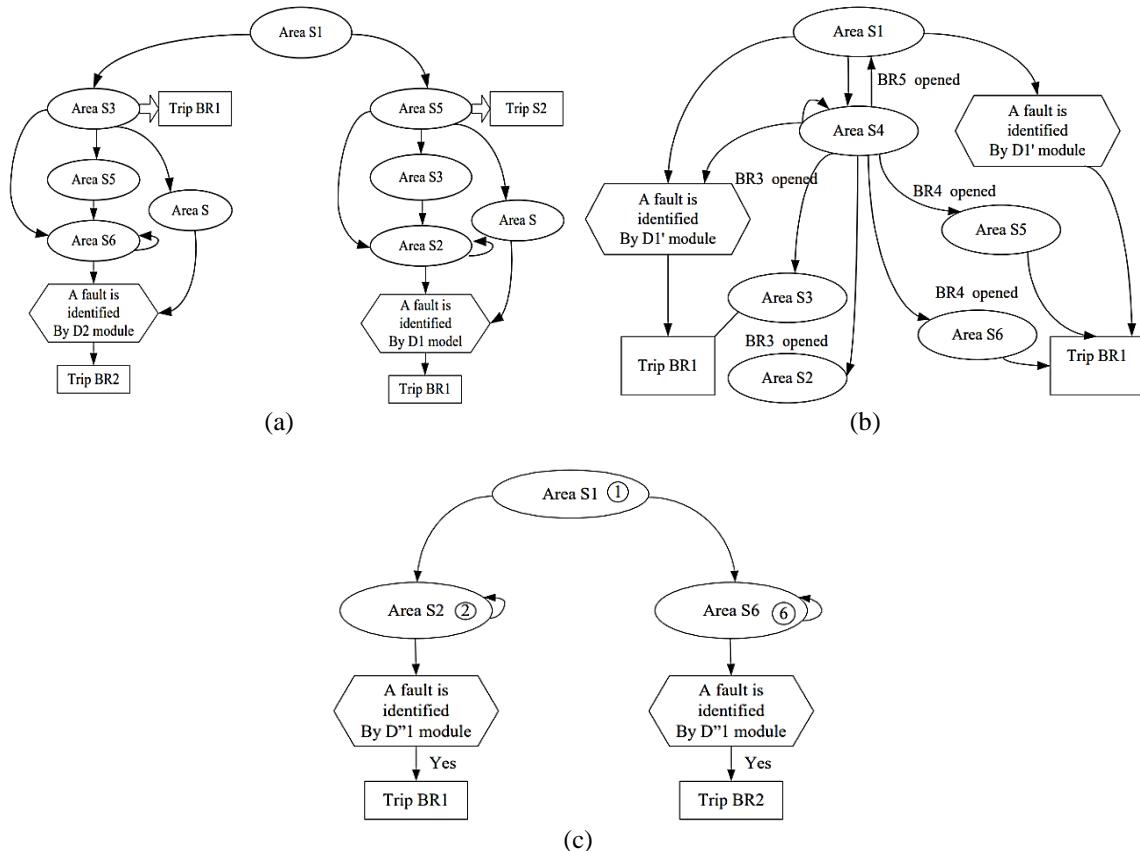


Figure 6. Proposed method (a) part I of the proposed algorithm, (b) part II of the proposed algorithms and (c) part III of the proposed algorithm

Table 3. The state transition for each circumstance in part II

Case	Events	State transition
1	External fault on the remote line, BR5 opened	1,4,1
2	A remote fault occurs on circuit 1, BR3 opened	1,4,3
3	A remote fault occurs on circuit 1, BR3 opened	1,,2
4	A remote fault occurs on circuit 2, BR opened	1,4,5
5	A remote fault occurs on circuit 2, BR4 opened	1,4,6
6	Inter circuit fault detected by relay D'1	1,4, D'1 output is high
7	External fault not detected by the associated relay, it can be identified by the 2 <sup>nd</sup> zone of D'1	1,4, D'1 output is high
	Inter circuit fault detected by relay D'2	1,4, D'2 output is high
	External fault not detected by the associated relay, it can be identified by the 2 <sup>nd</sup> zone of D'2	1,4, D'2 output is high

#### 4. CONCLUSION

The mutual couple effect is affecting the operation of the relay. It causes the relay to underreach or overreach. This paper introduces a new algorithm to protect the parallel transmission line from the mutual coupling effect. The new algorithm used a two-dimensional space state diagram which used information at the remote location of the relay. An impedance-based technique and the cross-differential method both contribute to the final result, which is then integrated using a schematic. To evaluate the current in the parallel connection of the transmission system, the cross-differential method is used. While using parallel circuits, the traditional cross-differential method algorithm must be disabled. A cross-differential method monitors the impedance-based approach, which dynamically modifies the mutual interaction based on the state of the

parallel circuit currents in discrete regions of 2-dimensional space. So, if any of the parallel circuits was not around and has been grounded at both endpoints, the zero-sequence current of the ground circuit can be used to counteract the relay's overreach issue.

A state diagram technique requires the sequence transition between different zones to diagnose the issues, allowing the relay to have sent the correct trip command to the correct CB. When both circuits of a parallel transmission line have become operational, the suggested methodology responds to transient conditions or modifications in the process with less than a cycle. Because of the good precision of the cross-differential methodology, it provides a quick response during a change in operation, even during the fault-clearing technique. In comparison with other methodologies, the suggested methodology accurately and consistently encompasses inter-circuit as well as evolving faults. Furthermore, it protects the lines end by sensing the operation of the remote-end CBs.

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